SPATIAL VARIABILITY OF WATER APPLICATION AND PERCOLATION UNDER CENTER PIVOT IRRIGATION

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ABSTRACT

The water distribution in two center pivot irrigated fields in eastern Colorado, USA was simulated for the 1998 growing season based on actual irrigation applications. The simulated application depths show significant differences in both water application depth and uniformity due to changes in topography and periodic operation of an end gun on the systems. The seasonal irrigation application information and soils information taken from the USDA-Natural Resources Conservation Service soil surveys and from laboratory analyses were divided into discrete zones, the data were input to an irrigation scheduling program, and the calculated daily water balance was used to estimate variability in deep percolation over the fields. The variability in water application and in available water holding capacity create significant spatial variability in deep percolation across the fields.

INTRODUCTION

Center pivot irrigation systems can supply highly uniform water applications when they are properly designed and when operated over level terrain in a consistent manner. The water application from center pivot systems in most situations is assumed to be uniform; however, significant changes in the water distribution can occur with both location and time.

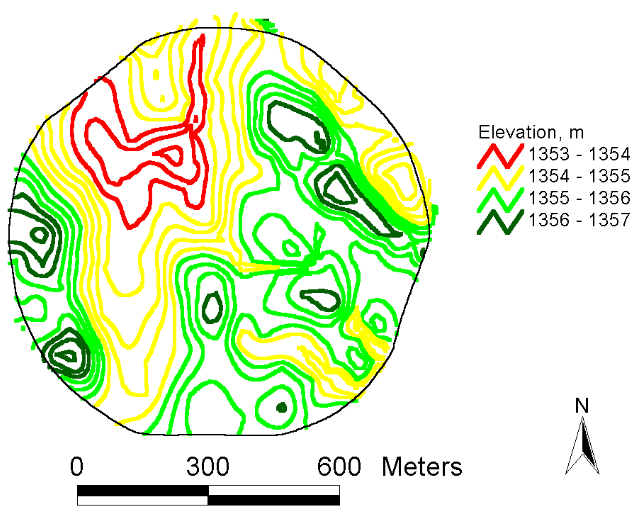
Variable topography changes the pressure distribution in the sprinkler pipe from that which occurs over level terrain. Both the discharge and wetted diameter by an individual sprinkler head are dependent on the operating pressure, therefore, variations in the pressure distribution affect the wetted area under a sprinkler head as well as the depth applied. When the elevation increases, the pipeline pressure is reduced at individual heads, resulting in lower discharge from those heads. The effects of topography on water distribution from center-pivots have been investigated by James (1982) and by Beccard and Heermann (1981). Both used simulation models based on the equations developed by Heermann and Hein (1968). Irrigation uniformity over an entire field was investigated by Evans *et al*. (1995) using computer simulation and a polar coordinate interpolation scheme.

Use of an end gun over segements of a field may also alter the center pivot water application characteristics. When the end gun is on, the pipeline flow rate and head loss increase and force the pump to a different equilibrium operating point than when the end gun is turned off. Thus, the pump supplies a larger flow at a lower head when the end gun is on and a smaller flow at a higher head when the end gun is off. The end result is a change in pressure distribution in different segments of the field, which can result in different mean application depths and different application uniformities if the sprinkler heads are not equipped with pressure regulators or flow control devices and if the machine speed is not changed to compensate for the different application rates.

Variability in the irrigation application as well as variability in the available water holding capacity create the potential for variability in deep percolation around the field. The objectives of this work were to use information about the topography, center pivot system, precipitation and soil characteristics to create maps showing spatial variability in center pivot water application and in deep percolation across a commercial center pivot irrigated field.

METHODS

The water application of two center pivot systems in eastern Colorado was simulated over their entire area of operation (Jordan *et al*.,1998). Each field was divided into zones of different soil type based on the USDA-NRCS soil survey information. The available water holding capacity of each type was estimated by pressure plate analysis. The irrigation water distribution, as affected by terrain and end gun operation, was simulated using the model developed by Heermann (1990) (USDA Center Pivot Evaluation and Design [CPED] program) which is based on the equations developed by Bittinger and Longenbaugh (1962) and solved by Heermann and Hein (1968). CPED solves the Darcy-Weisbach equation to determine pressures at each head along the machine, taking into account changes in topographic elevation. Then it simulates water application based on manufacturer specifications of the pump and sprinkler heads. Manually measured raingauges were distributed at 6m intervals along several radii representing topographic extremes to validate the results of the simulation program. Following this validation, operation of the center pivot was simulated at five degree increments around the full circle to account for variation in topography as shown in Figure 1.



. FIGURE 1. Topographic elevation map (m) for field A

Deep percolation was estimated using the USDA irrigation scheduling program, SCHED (Buchleiter, 1995), which calculates a daily water balance based on uniform irrigation application, precipitation, evapotranspiration and soil and crop characteristics. The evapotranspiration is calculated using a modified Penman equation. Crop rooting depth is assumed a linear function of time from crop emergence to full crop cover and ranges from 150 mm to 760 mm at this site. The program was run for the 1998 growing season, simulating actual irrigation applications for each soil type within the field and for three water application ranges within each soil type. First, the mean application depth was assumed evenly applied to the entire field, then the daily water balance was calculated for each field over the entire season based on the actual irrigation applications. Then each field was segmented into zones having similar available water holding characteristics and irrigation application depths, and the daily water balance was computed for the entire season over each of these water/soil zones.

The details of the water/soil zone simulation will be presented for field A, a 52 ha commercial field in eastern Colorado. An elevation surface was created by detailed topographic survey, which showed a maximum elevation change of 6 m across the field. This surface was used to estimate the tower elevations at each 5 degrees of azimuth using a geographic information system (GIS). Individual polygons of dimension tower radius plus or minus 6.1 m by five degrees (polar coordinates) were created for each five degree increment and overlaid onto the elevation surface. The mean elevation within each polygon was calculated and assumed to represent the elevation of each tower as it moved through a five degree arc, for input to CPED. Water application depth was determined by can tests, and pump discharge, pipeline pressure, and individual sprinkler flow measurements were made to verify the simulation program results.

The simulation program outputs application depths at a user specified interval of pivot radius. Application depth at simulated point was associated with cartesian coordinates to allow mapping. These points were then overlaid onto a polar grid because a center pivot irrigation system moves in a polar reference system.

Seasonal water distribution was analyzed using an area weighted mean seasonal application depth and a seasonal uniformity coefficient. The seasonal uniformity coefficient is the Heermann-Hein uniformity coefficient for center pivot irrigation machines (ASAE, 1996) calculated using the sum of the simulated irrigation depths from each irrigation event during the season. The polar grid map was then divided into zones defined by the available water holding capacity and three water application ranges. The application ranges used for each irrigation event are less than the field mean-5%, the field mean ± 5%, and greater than field mean + 5%. Precipitation was assumed to be uniformly distributed across the field at the time and in the amount measured at an adjacent meteorological station. SCHED was then used to calculate a water balance for each application depth range within each soil type.

RESULTS AND DISCUSSION

Mean seasonal application for field A was 640 mm. Water application profiles were also analyzed at individual azimuths. Weighted mean seasonal application depths along a given radius varied from 596 mm to 714 mm around the field, with the greater depth resulting from the large slopes the system operates over and the lower depths resulting from the areas where the end gun is on and where there is an increase in elevation in the north west section of the field. Individual application profiles show larger differences in the outer portion of the system (approximately 200 meters to the end). In this section of the system, differences in the seasonal application depths range from 114 mm to 203 mm. The outer area of the system where these large differences occur covers approximately 28 hectares which is approximately 54% of the total cultivated area. Figure 2 shows the seasonal irrigation application distribution over the field. The eastern half of the field has a larger seasonal application because the system was moved over an angle of about 125^{o} without irrigating during one irrigation event. The seasonal water application uniformity coefficient for the field is 0.88.

The USDA-NRCS soil survey shows the field to contain Bijou loamy sand (0-1 percent slopes), Valentine-Dwyer sand (terrace), Valentine sand (hilly) and Truckton loamy sand (3-5 percent slope) in five distinct zones. Field samples from the entire area were analyzed by pressure plate to estimate the available water holding capacity. These values were averaged within each soil zone, and the average water holding capacity used to calculate the daily water balance throughout the season. Figure 3 shows the sample locations, soil boundaries and average available water holding capacity.

The seasonal deep percolation was first estimated using the water balance program and assuming that water application is uniform over the entire field, as is available water holding capacity. For field A, the estimated mean seasonal deep percolation was 90 mm. Then seasonal deep percolation was estimated from the water balance in each of 15 zones (5 available water holding capacity zones and 3 irrigation application depth

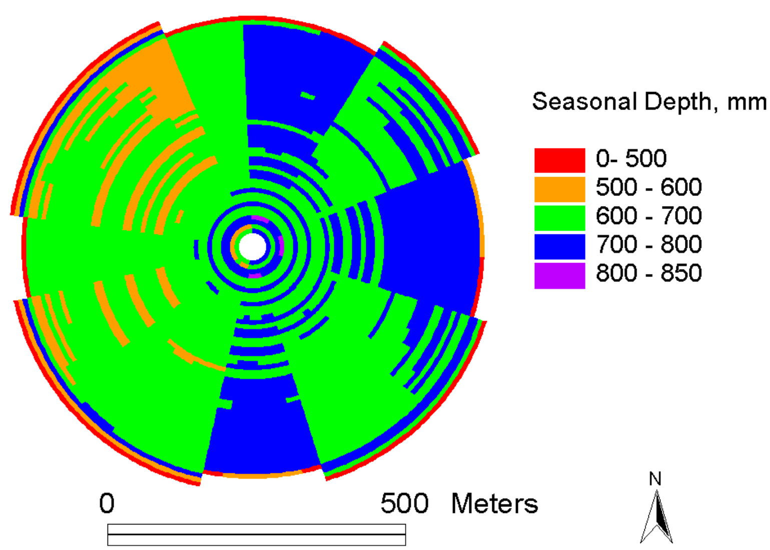


FIGURE 2. Seasonal irrigation application (mm) for field A, 1998

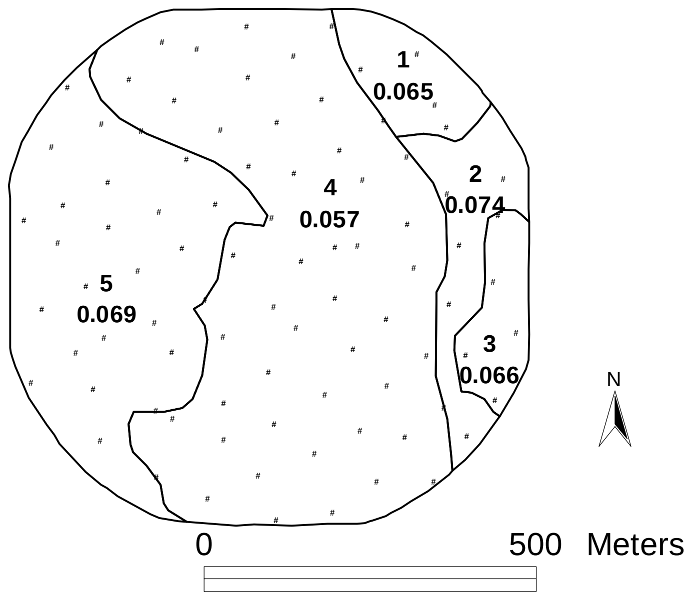


FIGURE 3. Soil sample locations (points), soil type boundaries, and average available water holding capacity (mm mm $^{-1}$) for field A, 1998.

zones). The estimated seasonal deep percolation resulting from variability in water application and available water holding capacity is shown in Figure 4. The central area of the field, which receives the largest amount of water and also has the lowest available water holding capacity in the field, contributed the largest amount of deep percolation,

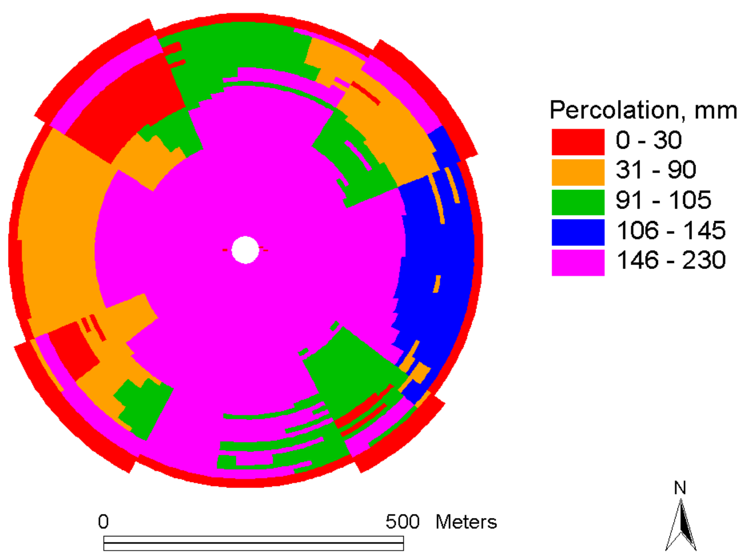


FIGURE 4. Estimated seasonal deep percolation (mm) for field A, 1998.

estimated at 146 to 228 mm. The east side of the field, which has a higher available water holding capacity than the center area yet receives high water application due to the large slope, produced the second largest amount of deep percolation.. The eastern half of the field also shows differences in the amount of deep percolation due to the different soil types present. The areas of the field receiving large amounts of water from the end gun also produced a large amount of deep percolation. The area weighted mean percolation from these 15 water/soil zones was 118 mm.

This analysis was repeated for field B, a second commercial field in eastern Colorado, which is mapped with four distinct soil series. The average water holding capacity was again determined for each soil series, and these values used in the SCHED program to estimate seasonal percolation. This field contains an area of relatively low water holding capacity in the northeast and a strip of high water holding capacity in the west (Figure 5). The variability in the seasonal deep percolation is shown in Figure 6. As in the case of the first field, both available water holding capacity and variability in water

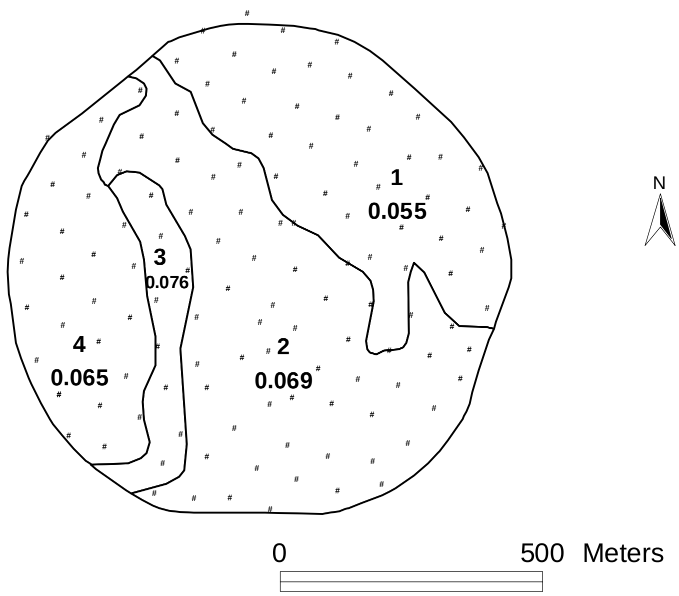


FIGURE 5. Soil sample locations (points), soil type boundaries, and average available water holding capacity (mm mm $^{-1}$) for field B, 1998.

application create a variability in the estimated deep percolation across the field. The largest amount of deep percolation occurs in the center of the field and in areas under the end gun. The areas in the north east and north west where the end gun is turned off are of particular interest in this field. Both areas receive higher amounts of water because the end gun is off, yet each area generated a different amount of deep percolation due to the differences in the available water holding capacity, with the north east area of the field having a lower value. When each irrigation was assumed uniform over the entire field, the seasonal deep percolation in field B was 111 mm. The area weighted deep percolation over the entire field, considering the twelve water/soil zones was 120 mm.

Considering both systems simulated, approximately two thirds of the volume of percolating water was contributed from half the irrigated area. Estimation of nitrate leaching resulting from percolation is beyond the scope of this presentation, but is planned as a future part of the continuing project.

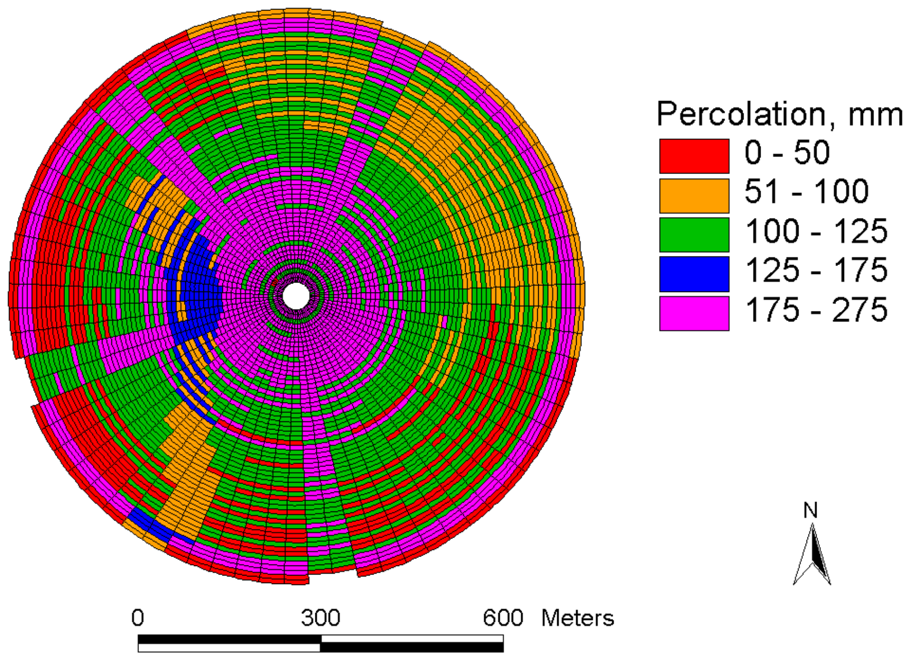


FIGURE 6. Seasonal deep percolation (mm) from field B, 1998.

IMPLICATIONS

The results reported here are an initial step in a long-term evaluation of precision farming under center pivot irrigated conditions in the central United States. The first two years of the study have been dedicated to collection of baseline data to determine the impact of typical grower management and existing variability upon crop yield (Heermann *et al., 1999)*. Subsequent studies will evaluate in greater detail the impact of design and practices, both current and precision farming, upon the environment and the economic consequences of precision farming.

Improvements to the irrigation system, such as renozzling, will be considered to achieve more uniform irrigation water distribution across the field. The effects of management improvements, such as adjustment of the end gun sprinkler arc, increasing the main system speed when the end gun is turned off, and removal of the end gun sprinkler altogether will be evaluated to determine both environmental and economic impact. By these improvements, we feel that we can improve the seasonal CU from the present 0.86 to 0.88 up to 0.95 or better. Such an increase in uniformity would reduce the total pumping requirement to achieve adequate irrigation on the "mean low quarter" by 15% (Duke, *et al.*, 1992), and correspondingly reduce the potential percolation.

Previous developments of methodology for varying the irrigation depth along the pipeline (Duke, *et al., 1997)* have demonstrated the potential for spatially variable irrigation. It may be feasible to adjust irrigations in response to changes in available water holding capacity, topographic slope, or infiltration rate to further minimize the potential for percolation and chemical leaching. Such methodology may hold particular promise in semihumid areas where the probability of natural precipitation increases the potential for percolation in soils of variable available water holding capacity.

We have also provided the growers with weekly irrigation scheduling information, based on recent meteorological data, yet asked them not to change their previous management practices. Comparison of irrigation history for 1998 with that of 1997 suggests, however, that the two growers are changing irrigation management practices in response to irrigation scheduling information provided. Careful management in accordance with estimated crop water use, and considering the short term probability of precipitation, may lead to further significant reduction in percolation of water and soluble agrochemicals.

A relatively inexpensive sprinkler mounted chemical spray system is also being developed in cooperation with a major center pivot manufacturer (Duke, *et al., 1997*). When used in conjunction with commercially available computerized pivot controls, this system allows control of individual segments along the pipeline so that agrochemicals can be applied only when and where they are needed as determined by real-time sensing. Such selective application has the potential of significantly reducing the level of inputs needed while maintaining or perhaps increasing crop yield.

CONCLUSIONS

The simulations show that intermittent operation of the end gun and variable topography will create spatial variability in the water application from a center pivot irrigation system. Management decisions, such as incomplete irrigations and poorly adjusted sprinkler heads, also significantly impact the seasonal water distribution. The variability in water application can be significant over the growing season and all differences in operating environment should be accounted for when evaluating the performance of a center pivot irrigation system.

Differences in the available water holding capacity across an agricultural field can produce variable amounts of deep percolation as well. The amount of deep percolation for specific areas of the fields studied appear to be dominated by water application in some instances and by available water holding capacity in others. Spatial variability in deep percolation will inevitably lead to variability in the amount of chemicals lost from the root zone. Both spatial variability of water application and available water holding capacity can therefore potentially lead to spatial variability in yield, and both factors should be considered in a precision farming environment. Although the area weighted mean estimated percolation differed little from the percolation estimated assuming uniform soil characteristics and water application, it is likely that chemical transport would be more accurately estimated by an approach which accounts for the variability across a field.

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